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A ONE-PHASE TARGETING CONCEPT FOR THE LM POWERED DESCENT

By James H. Alphin,
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MISSION PLANNING AND ANALYSIS DIVISION

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PROJECT APOLLO

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Mission Planning and Analysis Division

FIGURES

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A ONE-PHASE TARGETING CONCEPT FOR THE LM POWERED DESCENT

By James H. Alphin

SUMMARY

The current lunar module (LM) powered descent guidance logic consists of two basic programs, P-63 and P-64, and requires two sets of targets; i.e., one for the braking phase and one for the approach phase. However, the guidance equations are sensitive to terrain variations and navigation errors near the end on the braking phase. This report presents a technique which not only desensitizes the guidance solution to the terrain variations and navigation errors but also satisfies the landing phase constraints. The method essentially combines the two phases; therefore, most of the P-63 program logic as well as the braking phase targets could be removed from the onboard computer. The main disadvantage of this technique is that the altitude at high-gate (the point at which the landing site becomes visible in the window) will not be explicitly controlled; i.e., is not a target parameter. However, the time duration that the landing site is visible exceeds the time required to satisfy the landing phase constraint associated with landing site assessment.

INTRODUCTION

The current nominal LM powered descent trajectory, described in reference 1, consists of three phases; braking, approach, and landing. Each phase is designed to satisfy particular constraints and goals. The braking phase must efficiently reduce the orbital velocity and produce a specific target condition called high-gate. The approach phase provides visual assessment (out-the-window) of the landing area. The landing phase is designed to be compatible with pilot manual control takeover and detailed visual assessment of the landing area. The primary guidance law is a quadratic equation controlling acceleration as a function of time. The quadratic acceleration is used throughout powered descent except for the last 20 seconds of the braking phase and the last 10 seconds of an automatic landing phase prior to vertical descent. These two portions use linear acceleration guidance.

When uneven terrain or navigation errors exist near the initialization of the linear guidance phase, update of the LGC state vector by the landing radar can cause pitch and thrust transients with the current guidance implementation. This may result in landing radar loss of lock, excessive state vector errors at high-gate, and a highly oscillating pitch ride for the crew. All of these results are undesirable; therefore, a study was undertaken to determine techniques which minimize these effects.

DISCUSSION OF POSSIBLE SOLUTIONS

The current implementation of the guidance logic for the LM powered descent trajectory (programs P-63 and P-64, ref. 2) is sensitive to landing radar (LR) updates due to uneven terrain and navigation errors near the end of the braking phase (as the guidance time-to-go becomes small). Several methods have been investigated to desensitize the guidance solution to these parameters. Three of these techniques are summarized below:

1. Reference 3 presents a technique which uses a "false high-gate target" (the braking phase is terminated when the time-to-go reaches 40 seconds). This method reduces the transients due to LR updates; however, there are several undesirable features associated with the method. The "false high-gate target" is below the lunar surface and results in an undesirable target condition even though the guidance logic is terminated prior to the phase termination. The "false high-gate target" will not lie on the nominal trajectory path; therefore, generation of the target parameters will require artificial techniques which do not yield controlled trajectory parameters. This also means that high-gate altitude is not explicitly controlled.

2. A second method of reducing the position and velocity errors resulting from the guidance sensitivity to the landing radar updates is to freeze the quadratic guidance constants instead of switching to a linear acceleration guidance. This method tends to smooth the transients; but, no major improvement is achieved to warrant the complexity to the onboard computations.

3. Investigations for improving the weighting factors applied to the LR data prior to updating the primary guidance and navigation control subsystem (PGNCS) have been and are continuing to be performed by Massachusetts Institute of Technology Instrumentation Laboratory (MIT IL) (ref. 4) and by several elements at MSC. This technique may prove fruitful, but no significant improvements are currently available.

The one-phase guidance concept which is the subject of the present report is described in the next section.

DESCRIPTION OF ONE-PHASE GUIDANCE CONCEPT

Targeting

The one-phase guidance concept, as the name implies, consists of a single quadratic acceleration guidance phase targeted to low-gate (prior to vertical descent). The targets are selected to provide a nominal trajectory similar to the current nominal approach during the landing phase (i.e., compatible with manual takeover by the pilot below 500 ft in altitude). The targets used for the present study are presented in table I. The targets used were not optimized; however, no ΔV penalty is incurred over the current nominal ΔV.

Trajectory

The nominal trajectory parameters for the one-phase concept along with the current concept are shown in figure 1. The powered flight trajectory is initiated at an altitude of 50 000 ft near pericynthion of a 60-n. mi. by 50 000-ft altitude orbit. A 7.5-second, two-jet RCS ullage period followed by 26 seconds at minimum DPS thrust is performed using a constant inertial attitude. This attitude is calculated in the LM guidance computer (LGC) by a prethrust program. The main descent guidance phase is entered next. The descent propulsion system (DPS) throttle is commanded to the fixed throttle point (FTP), and the quadratic guidance logic enabled. At an altitude of 25 000 ft, the LR starts providing updates to the LGC navigation equations. At an elapsed time of 380 seconds (15 000-ft altitude), the guidance command drops below 57 percent, and the guidance assumes control of the DPS throttle. At 9000 ft, i.e., high-gate, the landing site is 5° above the bottom edge of the window. At the low-gate point (pilot takeover occurs at T_{go} = 57 seconds), the altitude is 800 ft; the range, 2000 ft; horizontal velocity, 82 fps; descent rate, 24 fps; and the look angle, 47.5° (22.5° above the window edge). The landing site is lost below the window at T_{go} of 18 seconds and a range of 150 ft. The elevation angle from the landing site to the spacecraft is 15° above the lower window edge for the last 126 seconds of the trajectory (below 4000-ft altitude). The final descent uses the current velocity nulling guidance.

The high-gate point, defined in the concept as the point at which the landing site is 5° above the lower window edge, is variable depending on the thrust dispersions and navigation errors. The nominal trajectory has a high-gate of 9000 ft with 170 seconds of visibility. For a 3σ low-thrust DPS, including redundant system operation, the high-gate point would occur at an altitude of 5000 ft and results in 140 seconds of visibility.

SENSITIVITY TO LR UPDATES

The sensitivity to the guidance concepts in the presence of FTP thrust dispersions, the III-P-11 landing approach terrain with and without terrain slopes was investigated. This site was chosen for the present study since it represents the roughest terrain of the prime Apollo sites. Figures which present time histories of trajectory parameters for both the current concept and the one-phase concept are provided to show the comparison between the two methods. Landings were to the near side of the landing ellipse.

In figure 2 is shown trajectory parameters for nominal thrust and for the terrain associated with the landing site III-P-11 (with 0° slope). As shown by the curves, the current guidance implementation has a large pitch deviation and a DPS engine pulse shortly before high-gate. This condition is eliminated by the one-phase targeting.

Figure 3 shows the results for the nominal thrust and III-P-11 terrain with a negative 1° slope. The current implementation does not exhibit as severe oscillations as for figure 2; however, undesirable pitch oscillations still exist. The one-phase targeting still does not require oscillations.

Figure 4 presents the trajectory parameters for the III-P-11 terrain with 0° slope and a high-thrust at the FTP. The current guidance logic requires an engine pulse to the FTP and large pitch oscillations. The one-phase targeting is nearly nominal except for the altitude rate profile and results in a high-gate at an altitude of 12 000 ft. However, the current guidance logic shows larger altitude rate changes above high-gate than the one-phase technique.

Figure 5 presents the results for a 3σ low thrust delivered from the DPS with the III-P-11 terrain including a -1° slope. The current targeting exhibits transients in thrust and pitch angle. The one-phase targeting shows a greater descent rate variation resulting in a high-gate of 6000 ft and reduced time for visual assessment of the site.

Figure 6 provides a comparison of two trajectories run with the one-phase concept. They represent the nominal from figure 1 and the low thrust with the III-P-11 terrain and the -1° slope of figure 5. Since these two cases show the largest change from the nominal, additional comment on the curves is needed. Figure 1(c), the thrust pitch angle versus time, indicates that the pitch angle is relatively insensitive to the dispersions. Figures 1(d) and 1(e), altitude rate and altitude, show that the low thrust changes the attitude profile; however, the low-thrust trajectory has an altitude of 6000 ft at high-gate. Figure 1(f), the flight-path angle, shows that the low thrust provides high flight-path angles. Figure 1(g), the landing point designator (LPD) angles, shows that the visibility time for the low thrust is shorter; however, the flight-path angle increase will improve the effectiveness of the visibility time. Table II shows the ΔV penalities for the cases used in this study for the one-phase and current concepts.

CONCLUDING REMARKS

The technique designated herein as one-phase targeting desensitizes the trajectory parameters during the powered descent maneuver to navigation errors and terrain variations (i.e., provides smooth pitch and thrust profiles). However, the trajectory parameters below high-gate vary over a wider range when subjected to thrust dispersion. The trajectories flown by the one-phase targeting satisfy the visibility and landing phase constraints and require no ΔV penalty. Further targeting studies will be required to optimize the trajectory parameters.

The method combines the braking and approach phases of powered descent logic; therefore, most of the P-63 program logic as well as the braking phase targets could be removed from the onboard computer.

TABLE I.- ONE-PHASE TARGETS

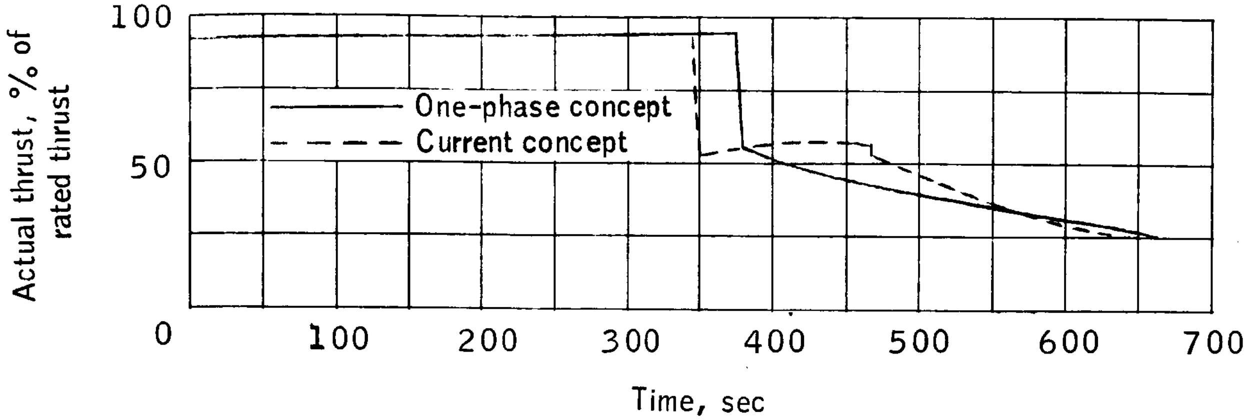
(Guidance coordinate system)

Parameter	X component	Z component
Position, ft	77.3334	1.7333
Velocity, fps	-3.3	-1.2
Acceleration, ft/sec^2 . .	+ .15	-6.5
Jerk, ft/sec^3	--	0.0206016

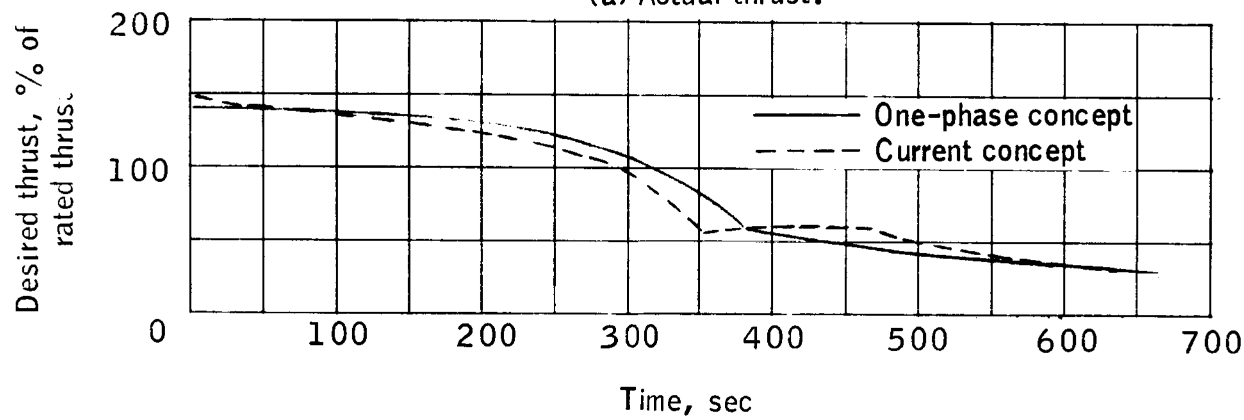
TABLE II.- COMPARISON ΔV PENALTIES FOR

THE ONE-PHASE CONCEPT AND CURRENT GUIDANCE

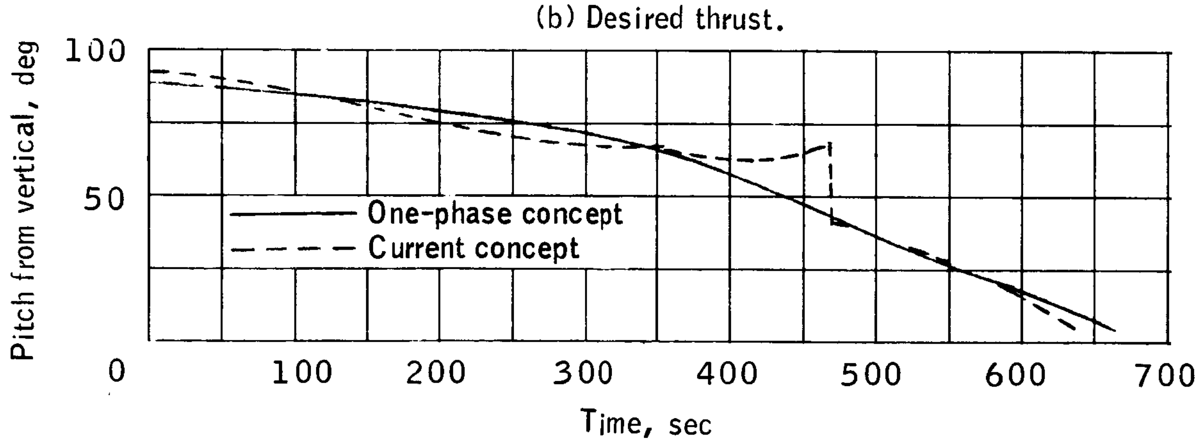
Case	ΔV	
	Current Guidance, fps	One-Phase Guidance, fps
Nominal	0	0
Nominal thrust; 0° slope	11	9
Nominal thrust; -1° slope	24	19
High thrust; 0° slope	25	10
3σ low thrust; -1° slope	-11	-161



(a) Actual thrust.

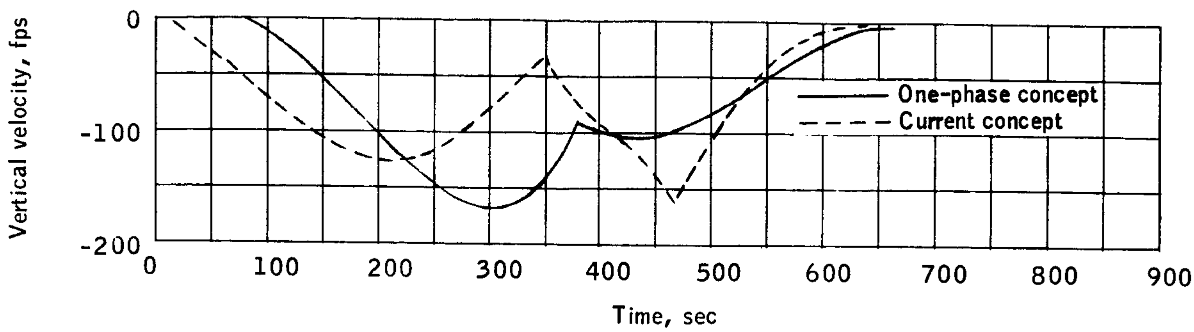


(b) Desired thrust.

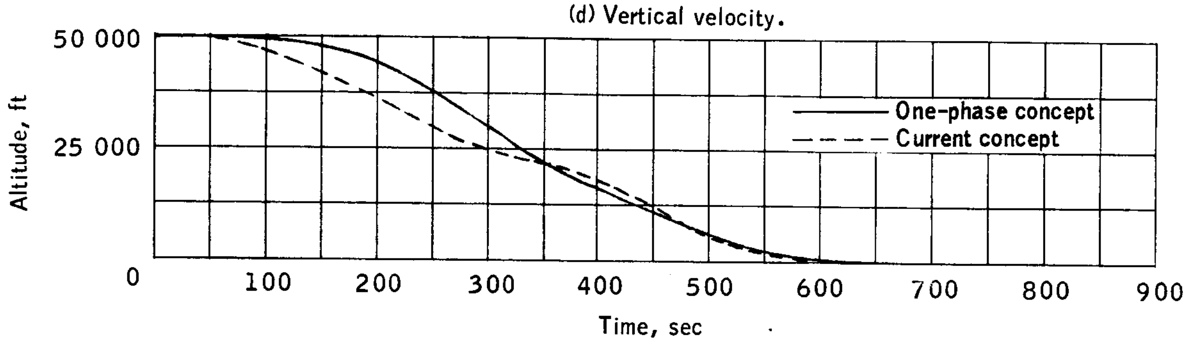


(c) Pitch angle.

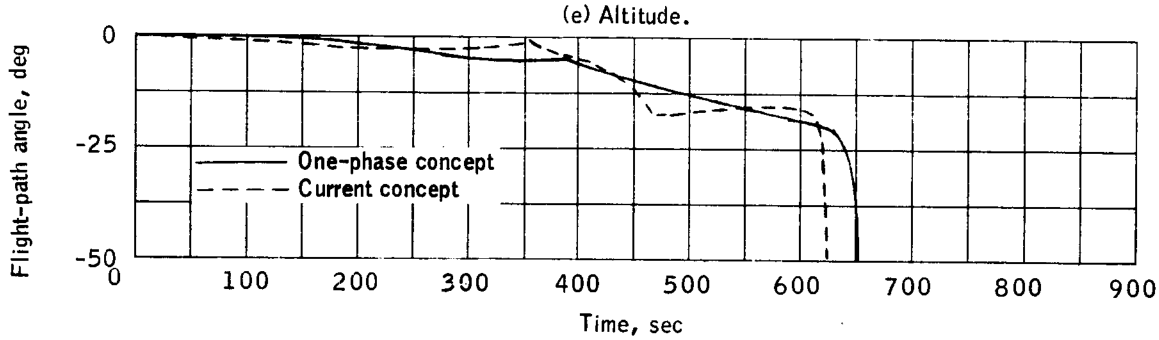
Figure 1.- Parameter time histories of a nominal descent for both the current and the one-phase concepts.



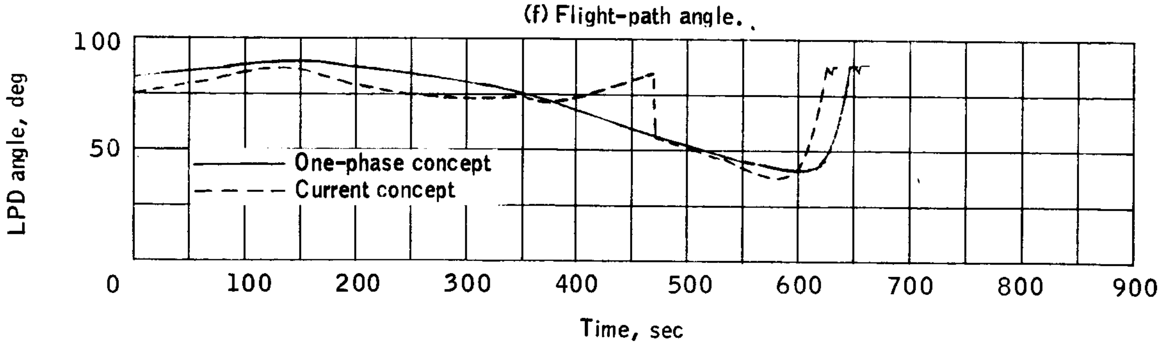
(d) Vertical velocity.



(e) Altitude.

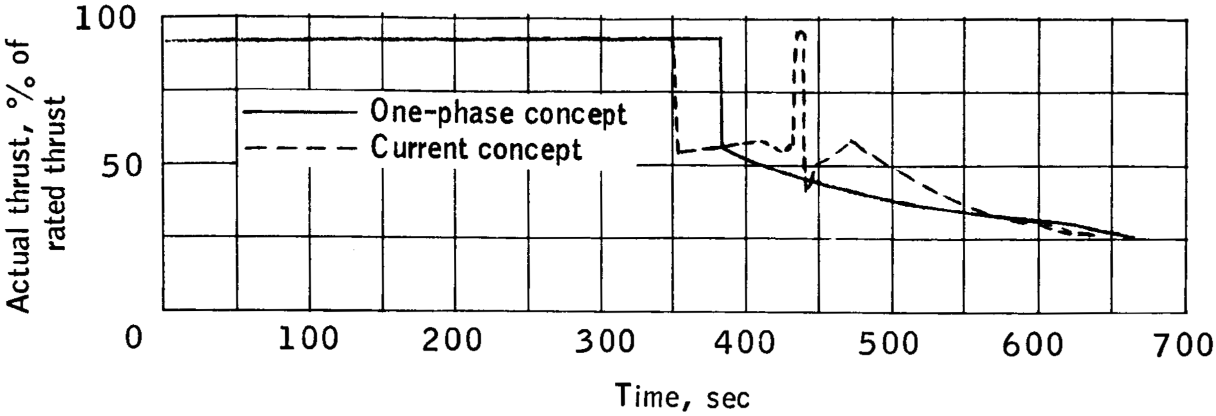


(f) Flight-path angle.

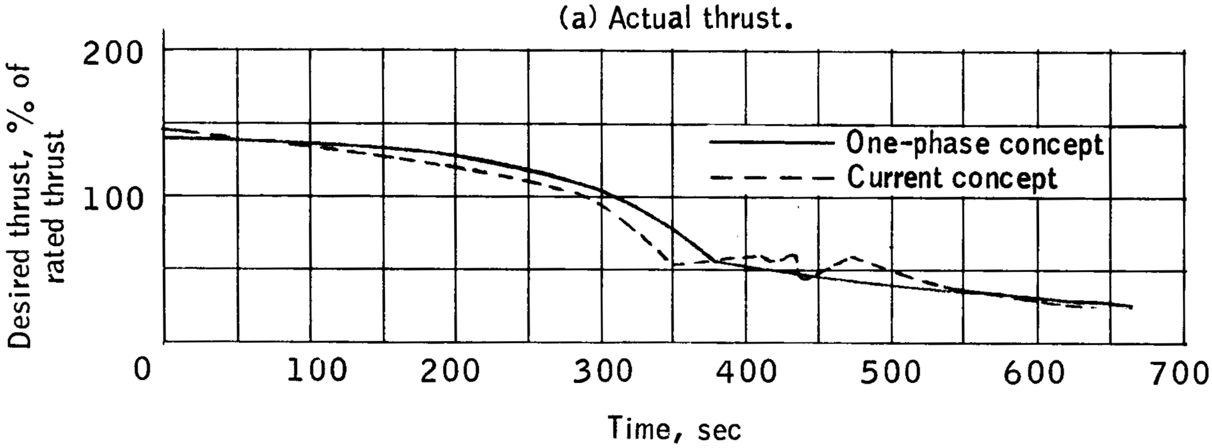


(g) LPD angle.

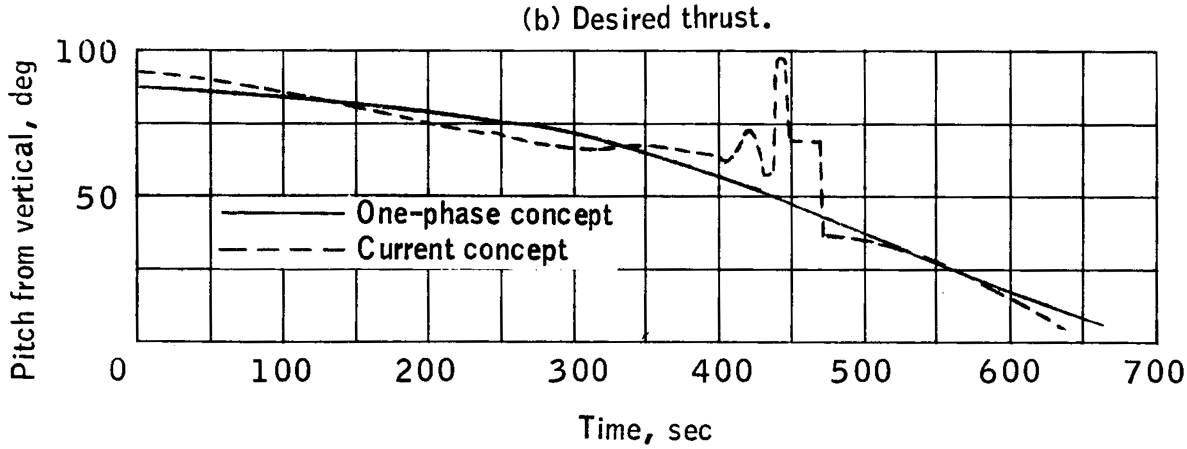
Figure 1.- Concluded.



(a) Actual thrust.

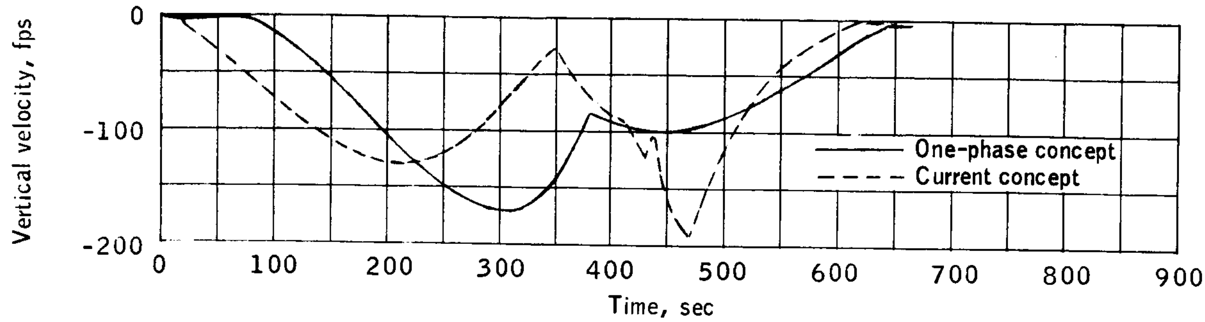


(b) Desired thrust.

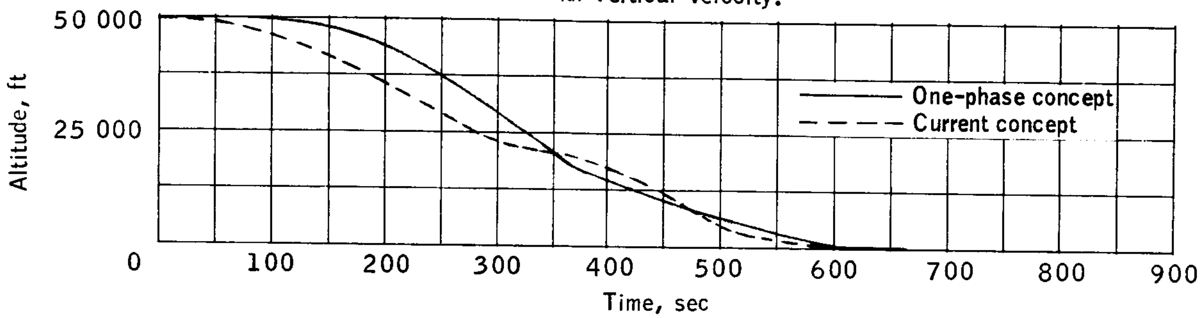


(c) Pitch angle.

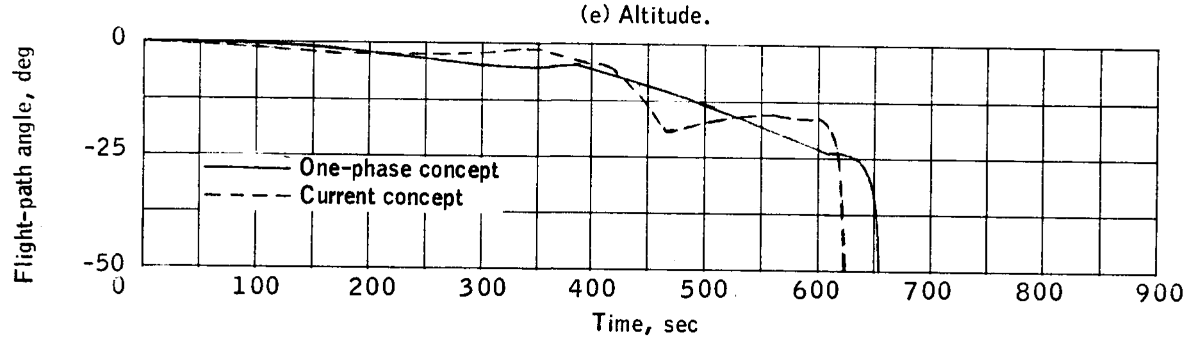
Figure 2.- Parameter time histories of a nominal thrust descent to III-P-11 with 0° slope for both the current and the one-phase concepts.



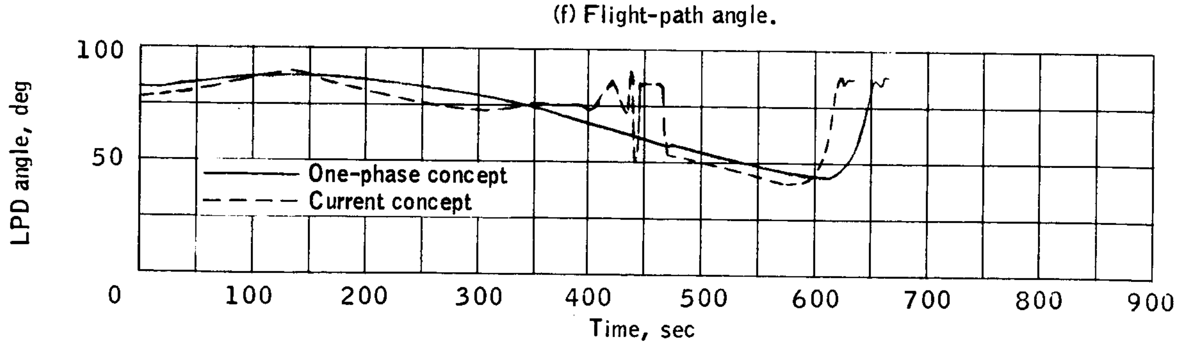
(d) Vertical velocity.



(e) Altitude.

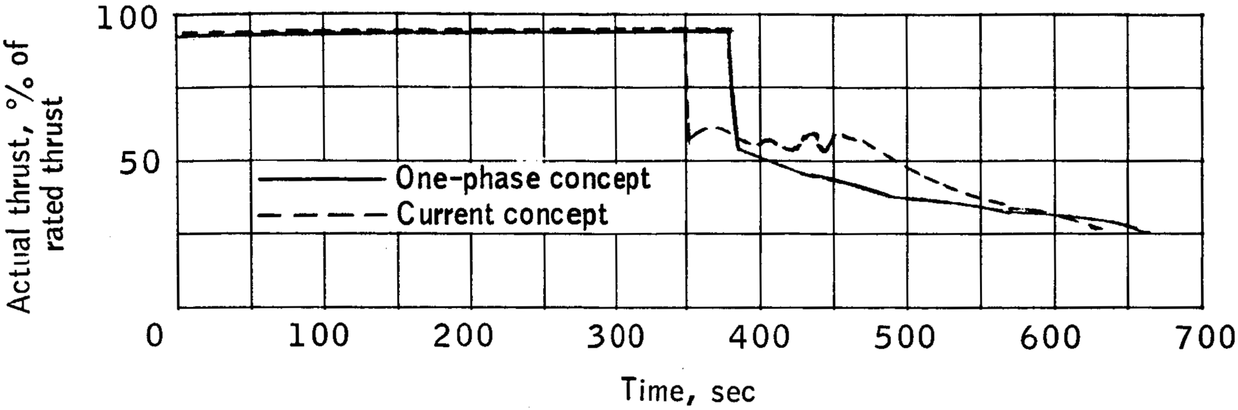


(f) Flight-path angle.

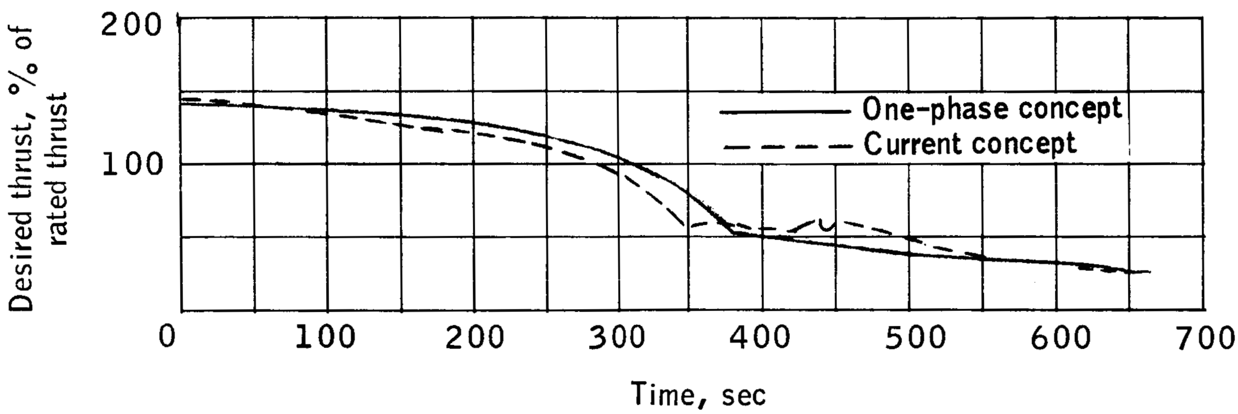


(g) LPD angle.

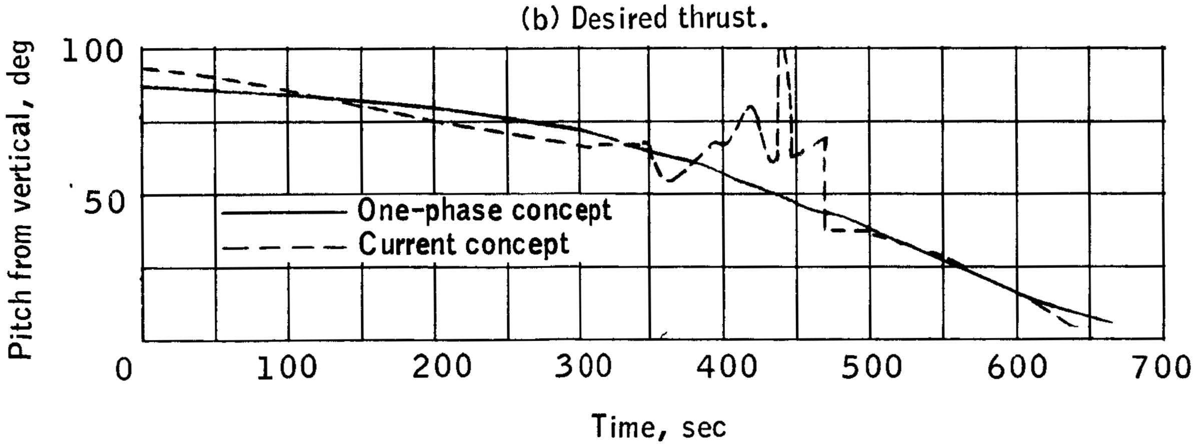
Figure 2.- Concluded.



(a) Actual thrust.

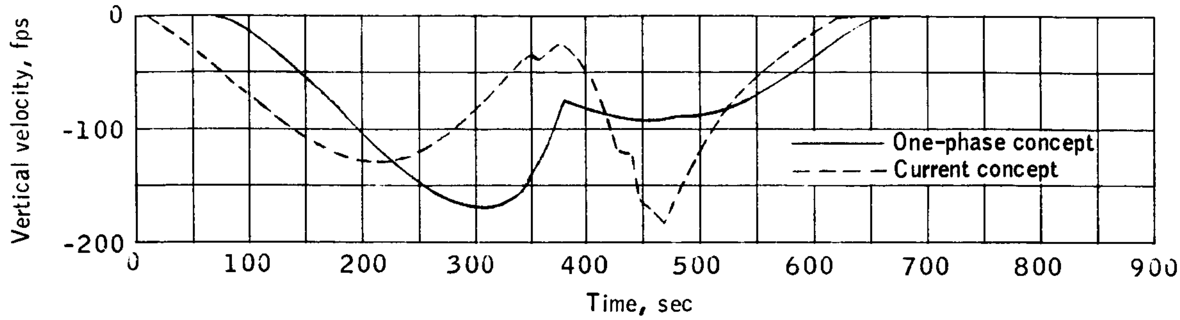


(b) Desired thrust.

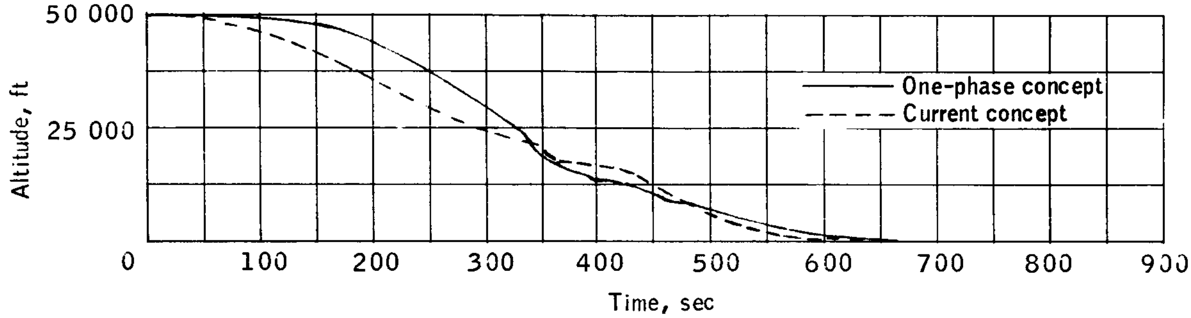


(c) Pitch angle.

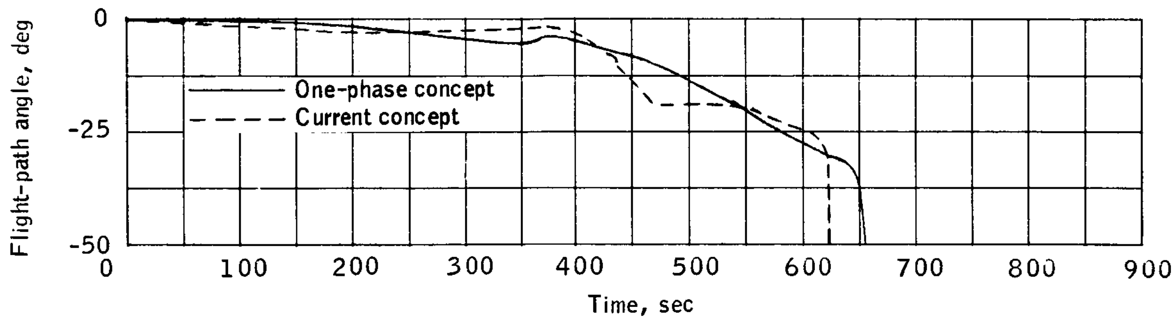
Figure 3.- Parameter time histories of a nominal thrust descent to III-P-11 with -1° slope for the current and the one-phase concepts.



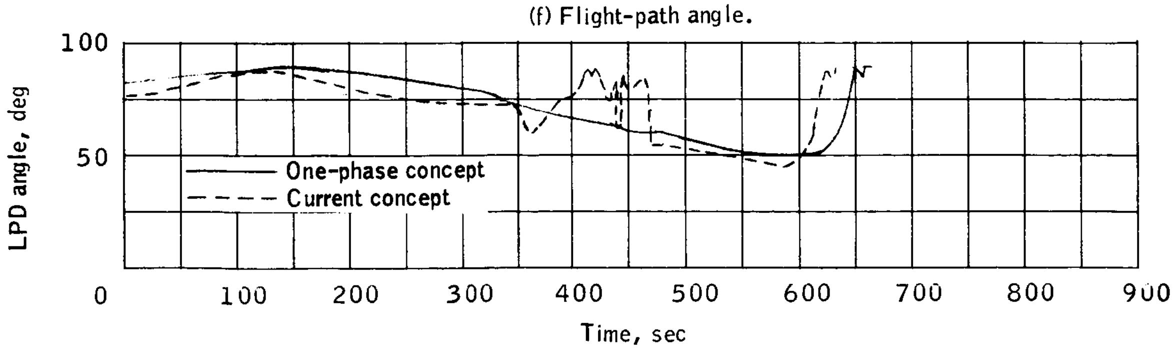
(d) Vertical velocity.



(e) Altitude.

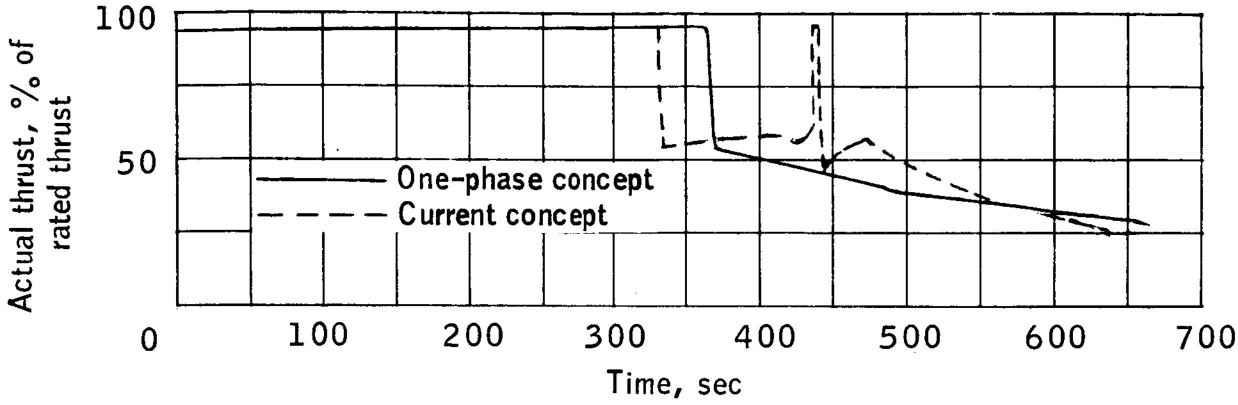


(f) Flight-path angle.

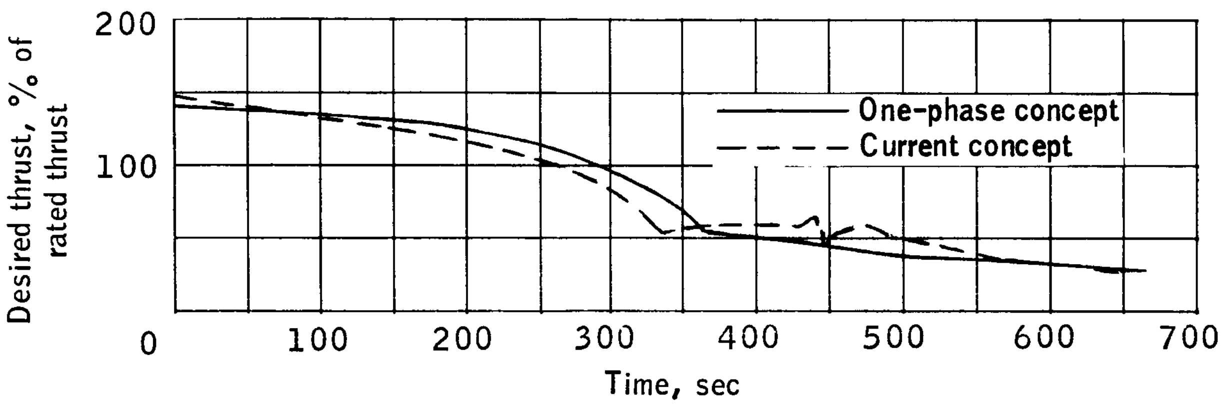


(g) LPD angle.

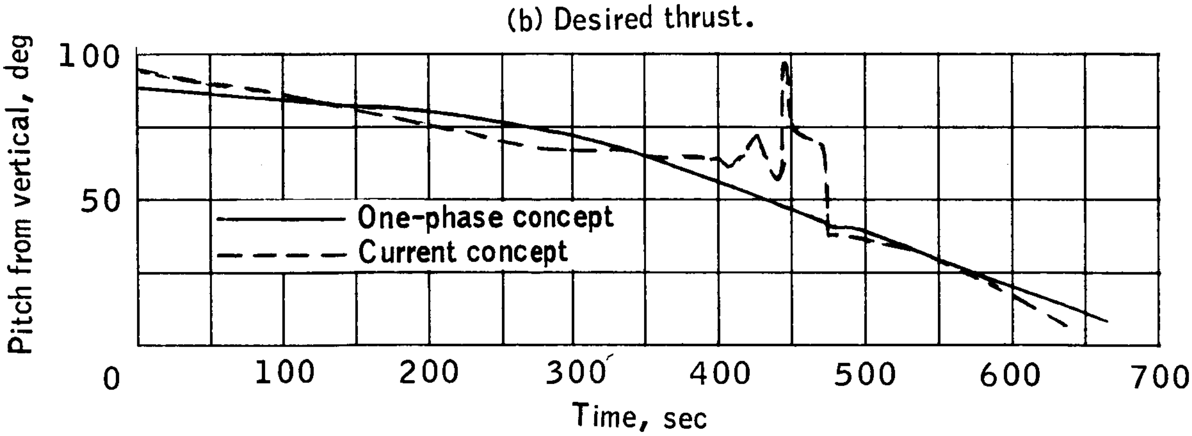
Figure 3.- Concluded.



(a) Actual thrust

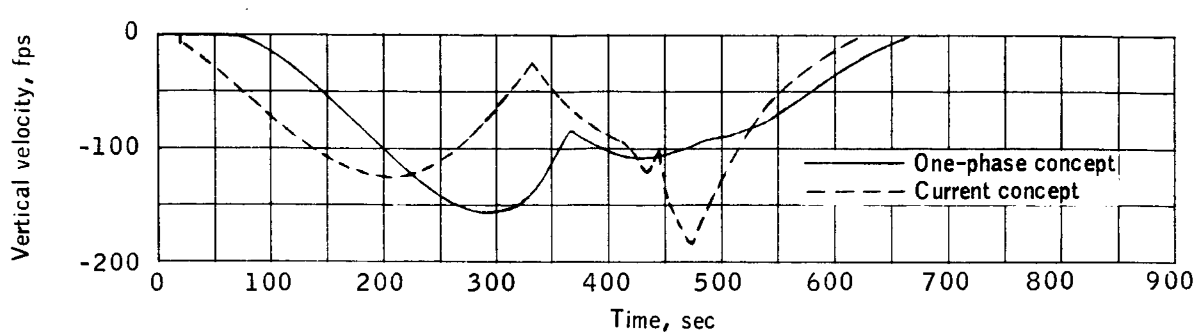


(b) Desired thrust.

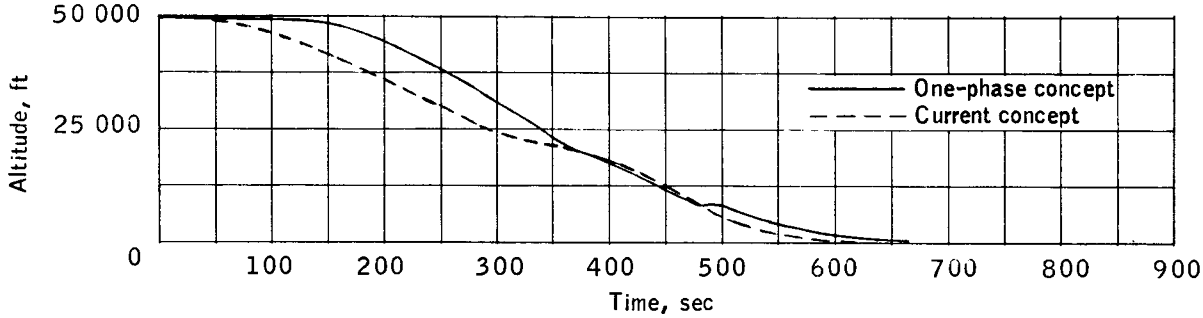


(c) Pitch angle.

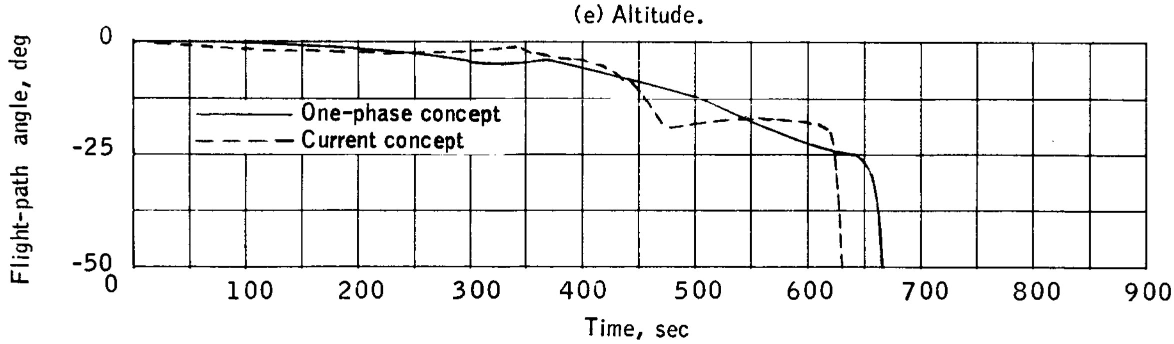
Figure 4.- Parameter time histories of a high thrust descent to III-P-11 with 0° slope for both the current and one-phase concepts.



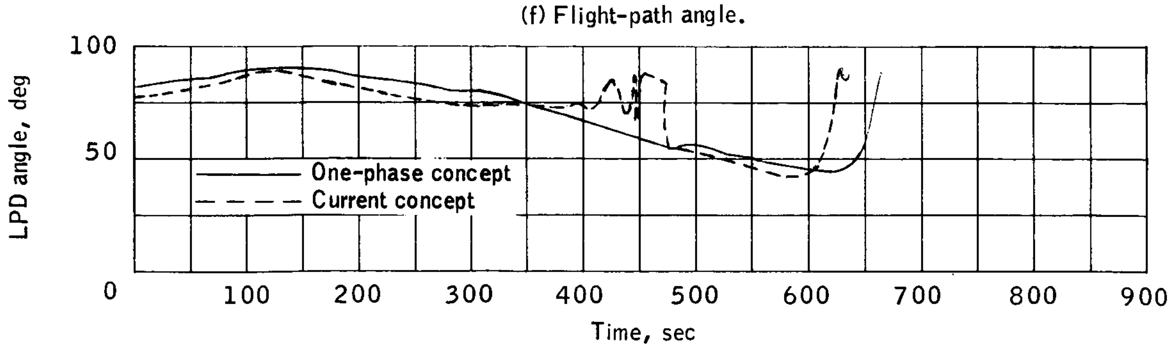
(d) Vertical velocity.



(e) Altitude.

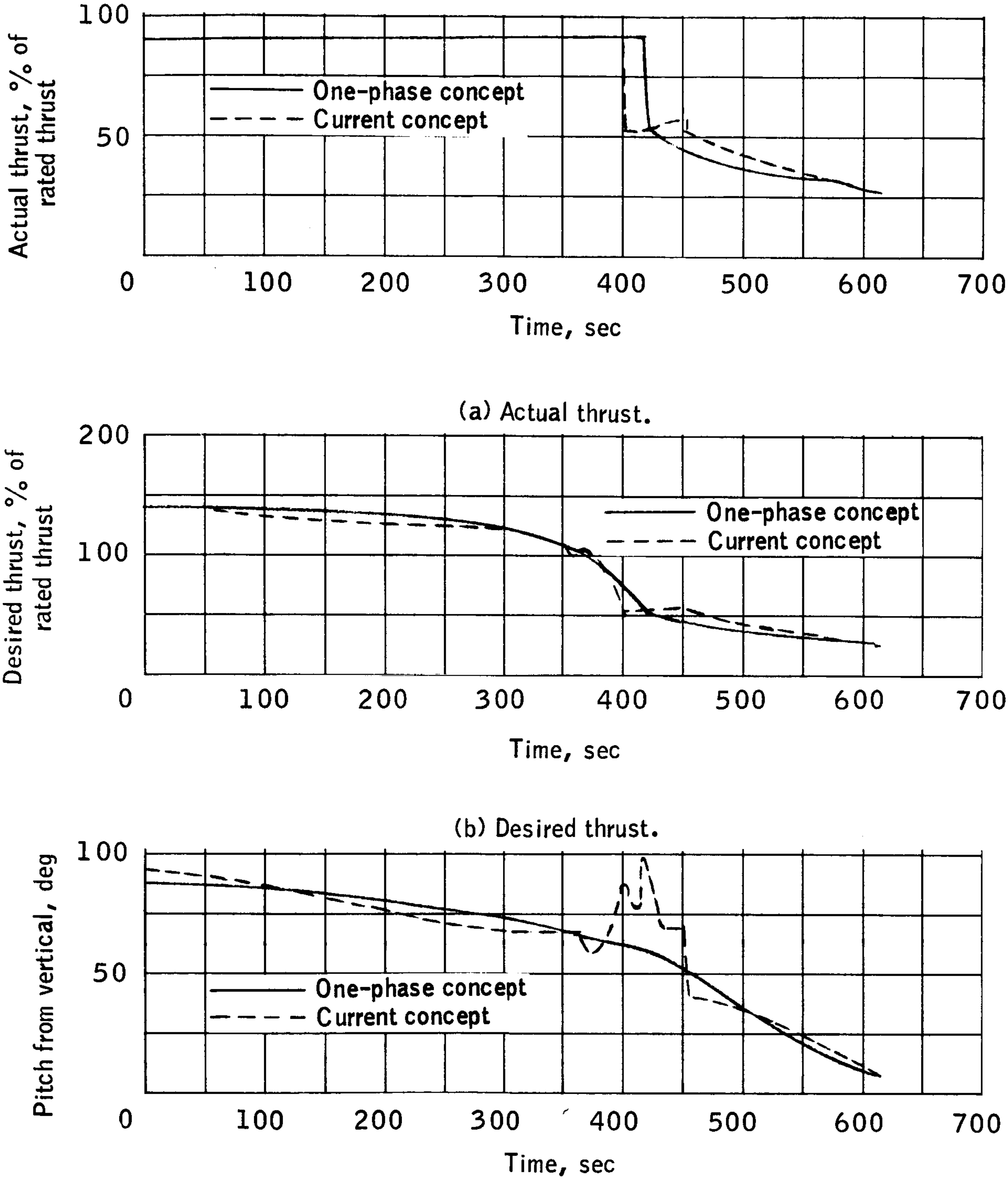


(f) Flight-path angle.



(g) LPD angle.

Figure 4.- Concluded.

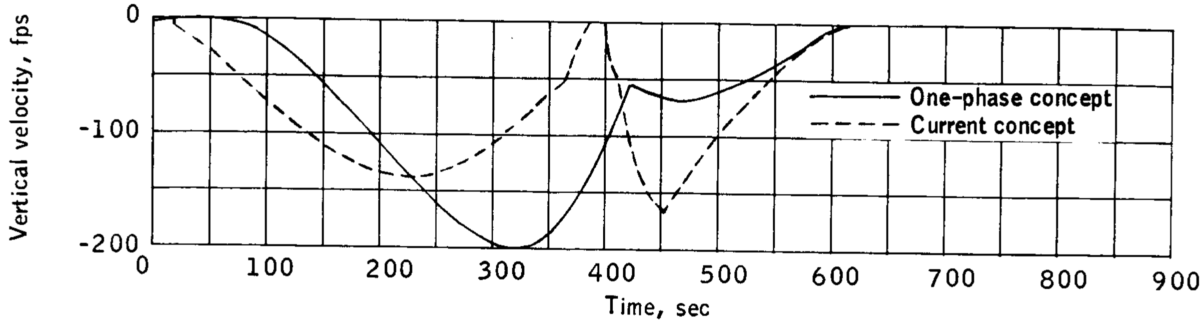


(a) Actual thrust.

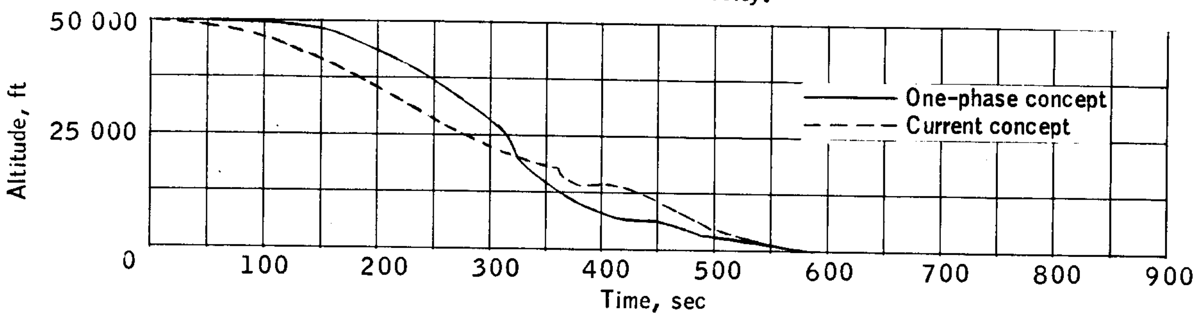
(b) Desired thrust.

(c) Pitch angle.

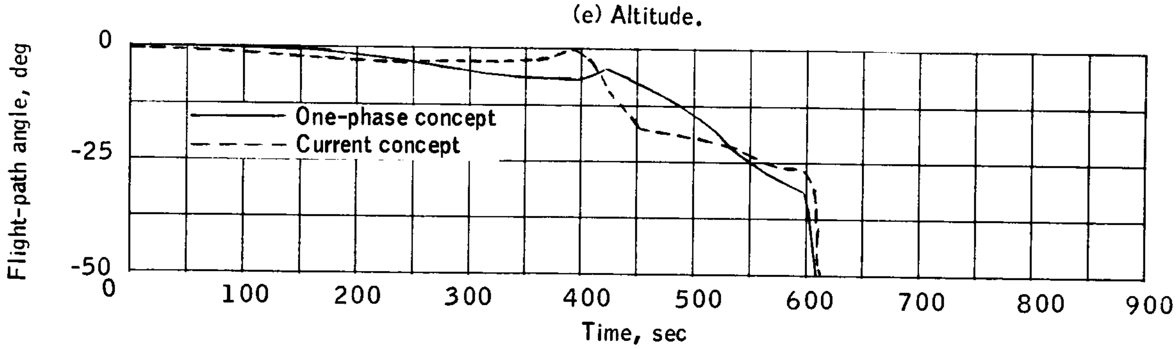
Figure 5.- Parameter time histories for a 3 σ low thrust descent to III-P-11 with -1° slope for both the current and one-phase concepts.



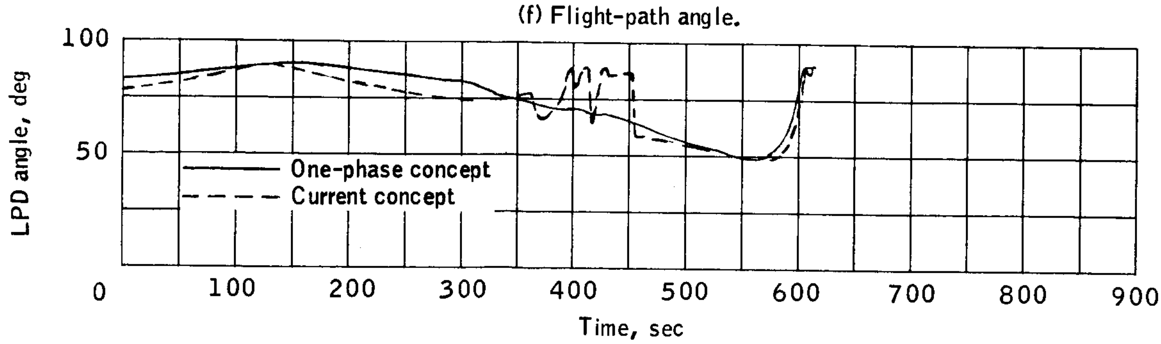
(d) Vertical velocity.



(e) Altitude.

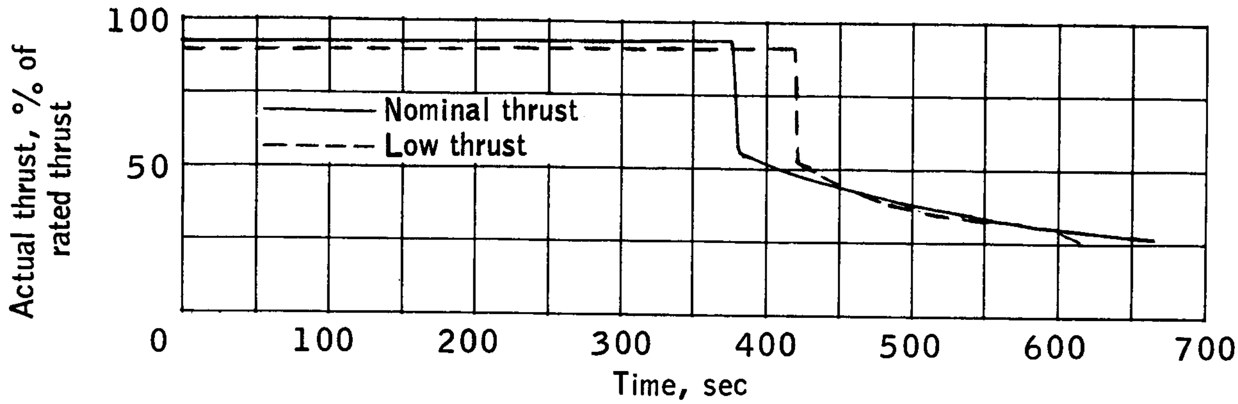


(f) Flight-path angle.

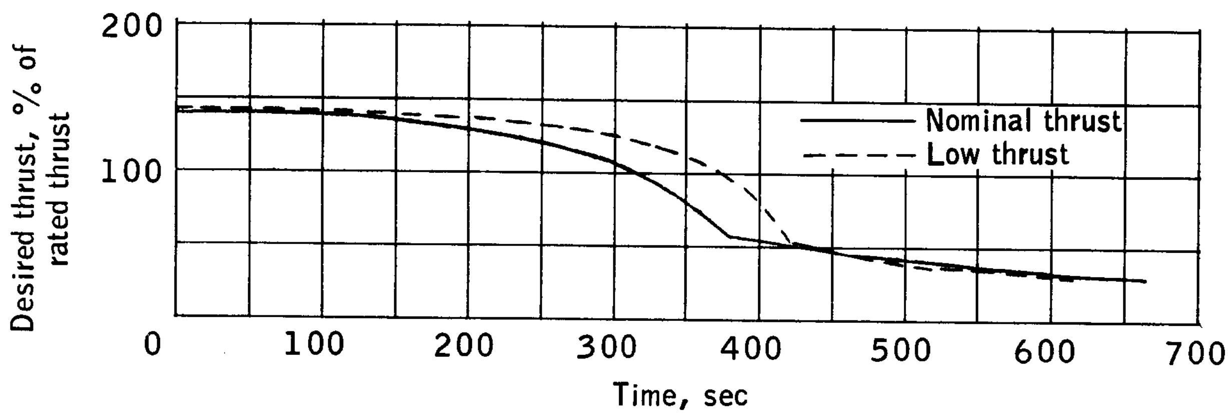


(g) LPD angle.

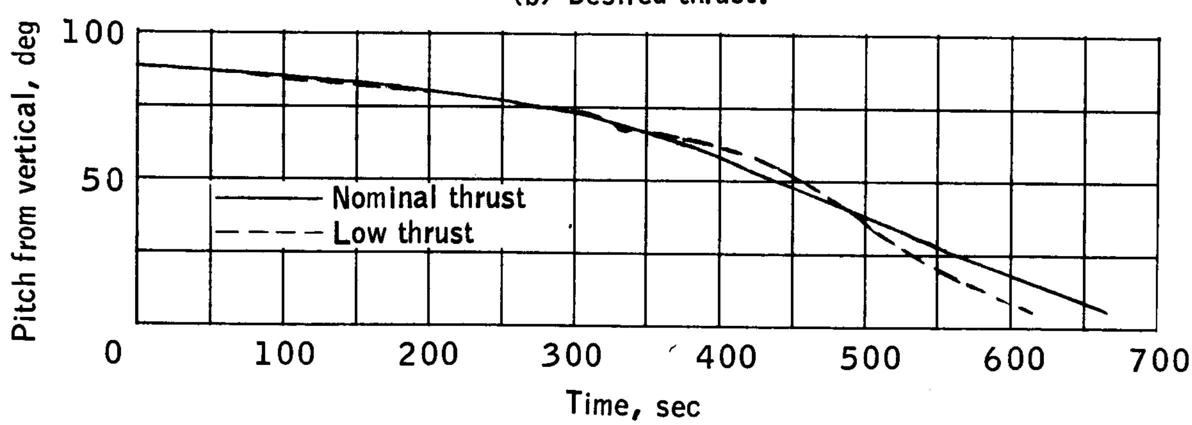
Figure 5.- Concluded.



(a) Actual thrust.

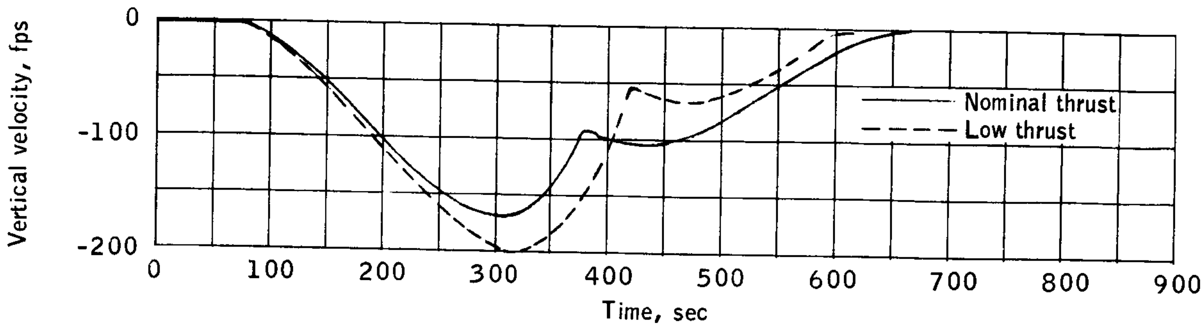


(b) Desired thrust.

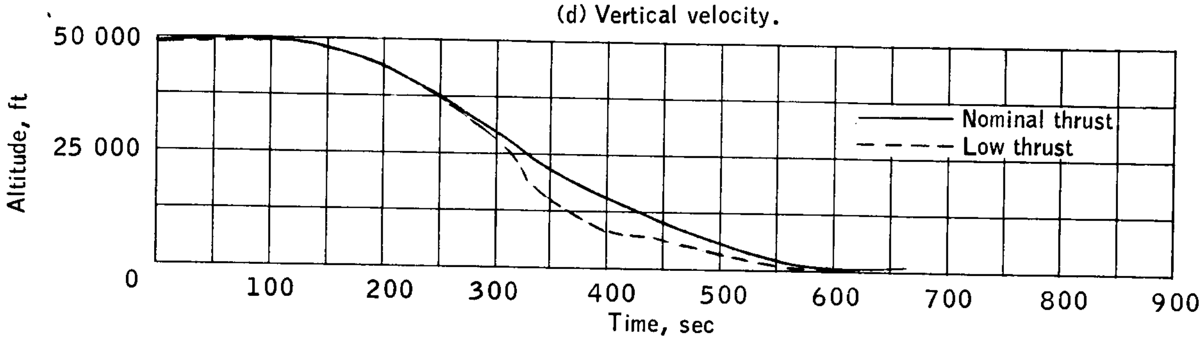


(c) Pitch angle.

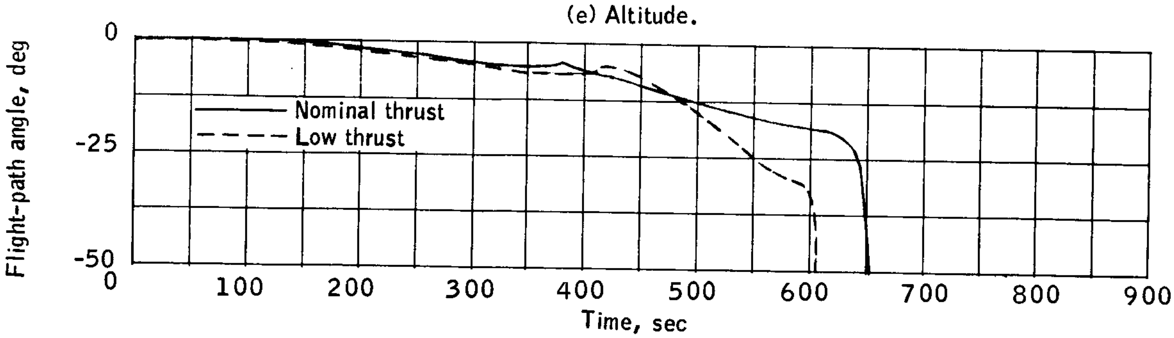
Figure 6.- Comparison of nominal descent (fig. 1) and 3σ low thrust descent to III-P-11 with -1° slope (fig. 5) for the one-phase concept.



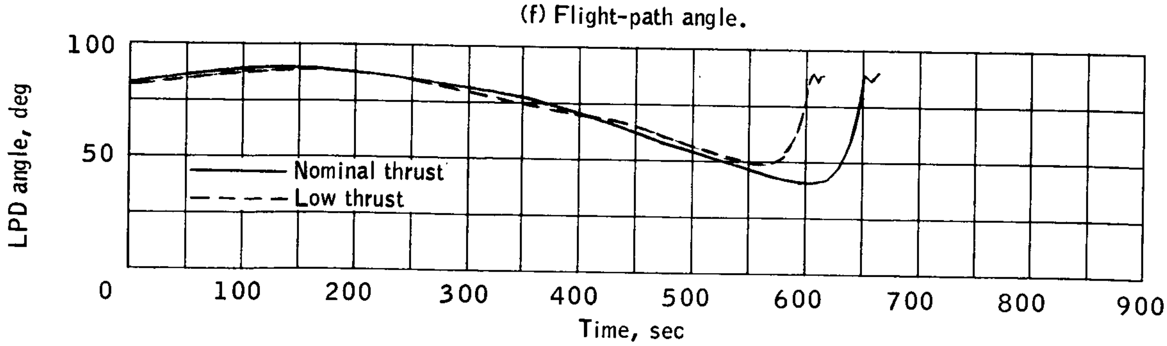
(d) Vertical velocity.



(e) Altitude.



(f) Flight-path angle.



(g) LPD angle.

Figure 6.- Concluded.

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